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The Patent Office
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1. Your reference — P186-GB

2. Patent application number *(The Patent Office will fill in this part)* — 0417277.1 — 3 AUG 2004

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*
1... Limited
St John's Innovation Centre
Cowley Road
Cambridge CB4 0WS

Patents ADP number *(if you know it)* — 8113894001

If the applicant is a corporate body, give the country/state of its incorporation — England

4. Title of the invention — Stereo Flat Loudspeaker

5. Name of your agent *(if you have one)* — Ursula Lenel

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*
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St John's Innovation Centre
Cowley Road
Cambridge CB4 0WS

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6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

YES

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Continuation sheets of this form	0
Description	6
Claim(s)	0
Abstract	0
Drawing(s)	3

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*

Request for preliminary examination and search *(Patents Form 9/77)*

Request for substantive examination *(Patents Form 10/77)*

Any other documents *(please specify)*

11. I/We request the grant of a patent on the basis of this application.

Signature Ursula Lenel Date 03-AUG-2004

12. Name and daytime telephone number of person to contact in the United Kingdom Ursula Lenel 01223-422290

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Notes

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Patent - Stereo Flat Loudspeaker

Prior Art

A co-owned patent application [PCT/GB02/02836] describes a flat loudspeaker device wherein a thin stiff panel of possibly transparent material is driven at one edge by a piezoelectric actuator of a novel C-shaped cross-section, with one "jaw" of the C-actuator bonded to the surrounded chassis/body/casework of the equipment housing the loudspeaker (hereinafter, the *Case*), and the other "jaw" bonded to one edge of the thin stiff panel. The remainder of the panel edges are resiliently mounted to the Case. The C-actuator, called a ***C-Morph***, is made of at least two piezo-electric ceramic layers sandwiched by at least 3 electrodes, in the manner of conventional "bender" device, except that instead of being flat, this C-Morph bender is curved into almost a full cylinder. In operation the C-Morph is driven from a suitable voltage current or charge source, with audio waveforms causing the C-Morph to bend around the axis of its cylinder of near-symmetry. This actuator bending imparts significant force on the edge of the thin stiff panel (relative to the Case) causing it to move in sympathy with the electrical driving waveform, and thus to radiate sound energy and hence function as a loudspeaker. The many advantages of this arrangement include: very thin profile allows fitting into confined spaces; the thin panel may be transparent (e.g. plastic, e.g. polycarbonate) and thus may be mounted over the front of a visual display as found e.g. in cellphones, PDAs, PC monitors, TVs etc, without taking up any extra significant panel space; relatively low drive power requirement due to the nature of the low-loss piezoelectric actuator; significantly improved low-frequency response due to the large radiating area; potentially sealable construction to prevent the ingress of moisture / water etc..

In its existing form, this prior art loudspeaker is capable of monophonic (single channel) operation only. In the same referenced patent an arrangement using two such devices is described as capable of providing stereo reproduction, but in no way differently from the arrangement of any two loudspeakers, separately driven and placed appropriately adjacent to each other. In particular, the stereo arrangement described in this prior art does not allow the stereo speaker arrangement to simultaneously form a single unbroken diaphragm surface that may be placed across a visual display without any discontinuity visible over the area of the display, because necessarily, if the two [separate] loudspeakers are placed in front of such a visual display both together covering the area of the display, there will be a physical join or gap between the two devices which will be practically impossible to make effectively transparent and non-intrusive.

In a further co-owned patent application [GB App # 0326721.8] a dual C-Morph actuator driven version of the above thin panel loudspeaker is described wherein opposed edges of the panel are connected to the two actuators, and preferably the same drive signal is applied to both actuators, the intent being to cause the thin panel to move more and in turn to move more air, and thus to improve the sound output of said loudspeaker.

The Present Invention

It is the purpose of the present invention to improve the flat loudspeaker device wherein a thin stiff panel of possibly transparent material is edge driven by a pair of opposed C-morph actuators, as described above in the prior art.

The First Aspect

In the first aspect of the invention, a thin flat panel driven by two actuators preferably of the C-morph variety and preferably identical attached along opposite edges of said panel, as otherwise described in the prior art [i.e. in the co-owned Application GB App # 0326721.8], and the two actuators are driven with separate electrical signals, VaL and VaR preferably via suitable piezoelectric drive amplifiers. VaL and VaR may be the two components VL and VR of a conventional stereo signal, for example, or more preferably they may be modified stereo signals where the low frequency components VLL and VRL below some cut-off frequency FL (e.g. FL = 400Hz is one of many such useful frequencies) of the two stereo channels VL and VR are first filtered out of the signals, leaving VLH and VRH; the filtered-out low frequency components VLL and VRL are then summed together producing one signal VLow, and finally VLow is summed back into each of VLH and VRH giving two separate signals VLC and VRC. These processed signals VLC and VRC are then applied as the two actuator drive signals VaL and VaR to the two actuators driving the panel. The nett effect is that at higher frequencies than FL the two signals VLC and VRC may be essentially independent and the two half-regions of the panel closest to the respective left and right actuators will predominantly radiate the sound represented by VLC and VRC respectively. At lower frequencies than FL both actuators will be effectively driven with the same signal (effectively just VLow) and the whole panel will tend to move as one, and more effectively radiate the low frequency components, such LF radiation-efficiency being generally proportional to the square of the area of the radiating part of the diaphragm or panel.

This approach works because as drive frequency increases the thin stiff panel tends to bend more and behave progressively less and less as a rigid co-moving body, whereas at very low frequencies it barely bends at all and operates effectively as a single stiff diaphragm. The art in building an effective speaker of this type is matching the stiffness of the panel to the crossover frequency FL so that useful independent radiation may be achieved above FL from the two halves of the panel adjacent to the left and right actuators, and useful uniform radiation from the whole panel below FL.

The Second Aspect

In a second aspect of the invention, the thin stiff panel that is driven by the two C-morph actuators is made non-uniform in its physical properties as a function of position on the panel. In a preferred embodiment of the invention the non-uniformity of the panel is symmetrical about the centre-line separating the two actuator attachment edges. In a further preferred embodiment of the invention the nonuniformity of the panel is made symmetrical about a line joining the centres of the two actuator drive edges. And in a further preferred embodiment the panel non-uniformities enjoy both these symmetries simultaneously.

In a further preferred embodiment any of the previously described non-uniform panel layouts is nonuniform in panel thickness (i.e. that panel dimension nominally at right angles to the panel's edges), with other panel properties held independent of position on panel. In this arrangement, with essentially uniform and isotropic panel material varying only in thickness over the panel, the panel ***stiffness***, which is a derived property of panel material (and thus material modulus) and panel thickness, will also vary over the panel. A preferred embodiment of thickness nonuniformity has the panel thinner along a centreline mid-way between the two driving actuators, which makes the panel less stiff along this central line, which assists with decoupling the separate acoustic radiation modes of the left panel half driven by the left actuator driven by signal VLC, and the right panel half driven by the right actuator driven by VRC, thus enhancing the stereo effect when heard by a listener in front of the loudspeaker. Where the thin panel (diaphragm) of the loudspeaker of the invention is to be used as a transparent, possibly protective, window in front of a visual display, it is an important further preferred embodiment to make only smooth changes of thickness of panel with position on the panel so as to minimise optical distortions by the panel of the image of the display behind said panel. A further preferred embodiment when the panel is transparent, and used as a display window as described, has the panel thickness profile smoothly increasing smoothly towards the centre line parallel to the two actuator driven edges, the panel then acting both as an acoustic radiator (loudspeaker) and display (cylindrical) lens providing some magnification of the underlying display to a viewer. A similar but different preferred embodiment for such a transparent display window panel loudspeaker, has the panel smoothly increasing in thickness towards a centre point near the geometric centre of the panel, so that there is a circularly symmetric thickness distribution, thinnest at or near the panel edges, as this has the possible advantage of acting like a spherical lens to magnify the display behind the panel.

In another preferred embodiment the material of the panel is inhomogeneous so that its density, or modulus, or both vary as a function of position on the panel, with various preferred distributions of these property variations being similar to the thickness variations described above, allowing for panels stiffer or less stiff towards the centre point or centre line(s) of the panel as required, without variation of panel thickness and the associated thickness-related optical effects. Note that varying the panel density and/or modulus may simultaneously vary the optical density of the panel as a function of position and so some optical lens-like effects may still occur even without panel thickness variations.

In a further preferred embodiment any and all combinations of physical parameter variations

described above may be combined in the one panel, so that for example, a panel might be thinner towards the middle, lower modulus towards the middle and higher density towards the edges, the variations of panel properties then being chosen to additively increase or minimise the associated optical effects where the panel is transparent, and/or to increase or minimise the dependent panel property, namely panel stiffness, as a function of position.

The Third Aspect

In the third aspect of the invention, any of the twin-actuator driven thin stiff panel loudspeaker variants described above, is fed with signals VxL and VxR to the left and right actuators respectively, where these two signals VxL and VxR have been processed so as to contain Head Related Transform Function (HRTF) information encoded in their waveforms, of the kind conventionally used in the many pseudo-stereo and pseudo-surround sound systems known in the art, such as the Stereo Dipole system designed by Nelson at ISVR Southampton. One of the requirements of such Stereo Dipole type systems is that the two separate radiating loudspeakers are preferably very close to each other, and in some cases the physical sizes of the transducers to be used are the limiting factor on just how close together they may be mounted in practice. In the speaker design of the present invention, suitable choice of actuator spacing, panel size, thickness, material and nonuniformity of physical properties, may be chosen to result in the dominantly radiating areas responsive to the left and right drive signals VxL and VxR, being almost any separation apart on the panel within the bounds of the panel area. That is, an *effective* acoustic transducer separation from almost zero up to the panel width may be achieved (even though the actuators driving the panel are fixed at the edges of the panel), and what is more, this effective transducer separation can be tailored to change with frequency if so desired. Thus a speaker of the design of the present invention may be used to produce stereo and surround sound for a listener suitably positioned, by application of HRTF processed signals to the left and right drive actuators, and furthermore, such signal processing may be combined with the low-frequency-cutoff processing described above, so that below a certain cut off frequency FL the speaker acted essentially as a single low frequency mono sound source.

These aspects and embodiments will now be illustrated by the drawings which are as follows:
Fig. 1 shows the basic layout of the twin actuator panel loudspeaker of the first aspect of the invention, with its two drive signals delivered to the actuators via drive amplifiers.
Fig. 2A shows the simplest stereo driving arrangement of the loudspeaker.
Fig. 2B shows a preferred means of driving the stereo signals to the loudspeaker so as to enhance the low frequency response and improve the higher frequency separation.
Fig. 3 shows a cross-sectional schematic of the loudspeaker when driven at low frequency by the same signal in the left and right channels.

uniformity of thin panel physical characteristics.

The drawings will now be described in more detail.
Fig. 1 shows the preferably thin preferably flat preferably stiff possibly transparent panel 12 attached at two of its opposing edges each to one of the "jaws" of a piezoelectric C-Morph actuator 21 and 22 on the left and right edges (in the drawing) respectively of panel 12, the opposed jaws of said actuators 21 and 22 being attached to the frame 11 of the loudspeaker housing equipment, said frame 11 being preferably stiff and relatively massive (to the panel 11). Actuators 21 and 22 are electrically driven by the drive amplifiers 15 and 16 respectively, said amplifiers having input drive voltages VaL shown as 17 and VaR shown as 18 respectively.

Fig. 2A shows the simplest method of driving the stereo loudspeaker of the invention, whereby stereo left 205 VL and right 206 VR input signals are connected directly to the inputs VaL 17 and VaR 18 of actuator drive amplifiers 15 and 16 respectively. In this drive mode the left section of the panel 12 will predominantly move in response to the left stereo signal 205 and the right section of the panel 12 will predominantly move in response to the right stereo signal 206 due to the closer proximity of the left and right actuators to the left and right edges of panel 12 and because of the finite stiffness of panel 12, and this left/right variation in motion of panel 12 will be more emphasised at high frequencies than at low frequencies. Thus stereo "separation" will be greater at higher frequencies than lower.

Fig. 2B shows a preferred way of driving panel 12 with stereo signals 205 VL and 206 VR, so as to maximise the possible low frequency output of the stereo loudspeaker. Signals 205 and 206 are applied to the inputs of frequency splitting filters 210 and 211 respectively, said filters having a characteristic frequency FLL and FLR respectively with FLL preferably equal to FLR, hereinafter described as FL. Frequencies higher than FL emerge from the two filters at outputs 213 VLH and VRH 216 respectively, whilst frequencies lower than FL emerge from the two filters at outputs 214 VLL and 215 VRL respectively. The low frequency outputs 214 and 215 are summed in signal summer/adder 218 to produce the output sum 217 VLOW which is added into each of the high frequency outputs 213 VLH by adder 219 and 216 VRH by adder 220, these adders producing sum outputs 221 VLC and 222 VRC respectively which are then fed on to the drive amplifiers 16 and 17 (not shown) via their inputs 17 VaL and 18 VaR.

The nett effect is that a low frequency (<FL) input signal component in either VL or VR (205, 206) (or both) is filtered by the filters 210, 211 and thus is absent from outputs 213 and 216, but is present in outputs 214 and/or 215 respectively, and emerges at the output of adder 218 as signal VLOW which is then added into *both* drive signals 17 VaL and 18 VaR by the adders 219 and 220 respectively, so that the whole diaphragm / panel 12 moves as one large more-efficient common acoustic radiating source, as illustrated in Fig. 3.

A higher frequency (>FL) signal component appearing at either input VL or VR (205, 206) is

filtered by the filters 219 and 220 so as to be absent from outputs 214 and 215 but present in outputs 213 or 216 respectively, and from there reach the appropriate drive signal 17 VaL or 18 VaR via the adders 219 and 220 respectively. Thus only the left 21 or right 22 side actuator is activated by a high frequency signal in the left 205 or right 206 input channel, thus localising the acoustic emission as mich as possible thus improving stereo separation, as illustrated in Fig. 4.

Fig. 3 is a cross sectional schematic of the loudspeaker showing the thin panel 12 mechanically connected to upper jaw of the left actuator 21 at its left edge, and the upper jaw of the right actuator 22 at its right edge, the lower jaws of both actuators 21 and 22 being mechanically attached to the Case 11. The dotted line 124 shows schematically the motion of the diaphragm/panel 12 when both actuators are driven by a similar low frequency signal and thus both driven edges of panel 12 are driven similarly and driven ***in phase***. This tends to cause the panel 12 to move as a rigid body at low frequencies although because of the rotational component of drive by the C-Morph actuators there will also be some bowing of the panel 12 as well, which contributes additional low frequency acoustic radiation to the loudspeaker output.

Fig. 4 is a cross sectional schematic of the loudspeaker showing the thin panel 12 mechanically connected to upper jaw of the left actuator 21 at its left edge, and the upper jaw of the right actuator 22 at its right edge, the lower jaws of both actuators 21 and 22 being mechanically attached to the Case 11. The dotted line 400 shows schematically the motion of the diaphragm/panel 12 when left actuator 21 alone is driven by a high frequency signal. The dotted line 401 shows schematically the motion of the diaphragm/panel 12 when right actuator 22 alone is driven by a high frequency signal. Because of the compliance of the diaphragm and its inertia at high frequencies, driving just one edge tends to localise the induced motion close to that edge and thus driving both edges of panel 12 simultaneously with ***different*** high frequency signals tends to produce localised different high frequency radiation schematically represented by 400 and 401 from the left and right sections of the panel 12 respectively, producing stereo separation.

Fig. 5 is a cross sectional schematic of the loudspeaker showing the thin panel 12 as before but in this schematic some indication of panel thickness and variation thereof is evident. In the sketch the panel 12 is thin near or at a centre region 520 while being substantially thicker on either side of this region at 510 and 530 for example. Fig. 5 also shows how the panel thickness changes smoothly with position on the panel, at least over any area used as a transparent possibly protective window over a visual display. Note that although Fig. 5 suggests that panel 12 thickness variations all occur on one side of the panel, in practice these variations may occur on either or both sides (i.e. one side may be flat, the other profiled, or both profiled).

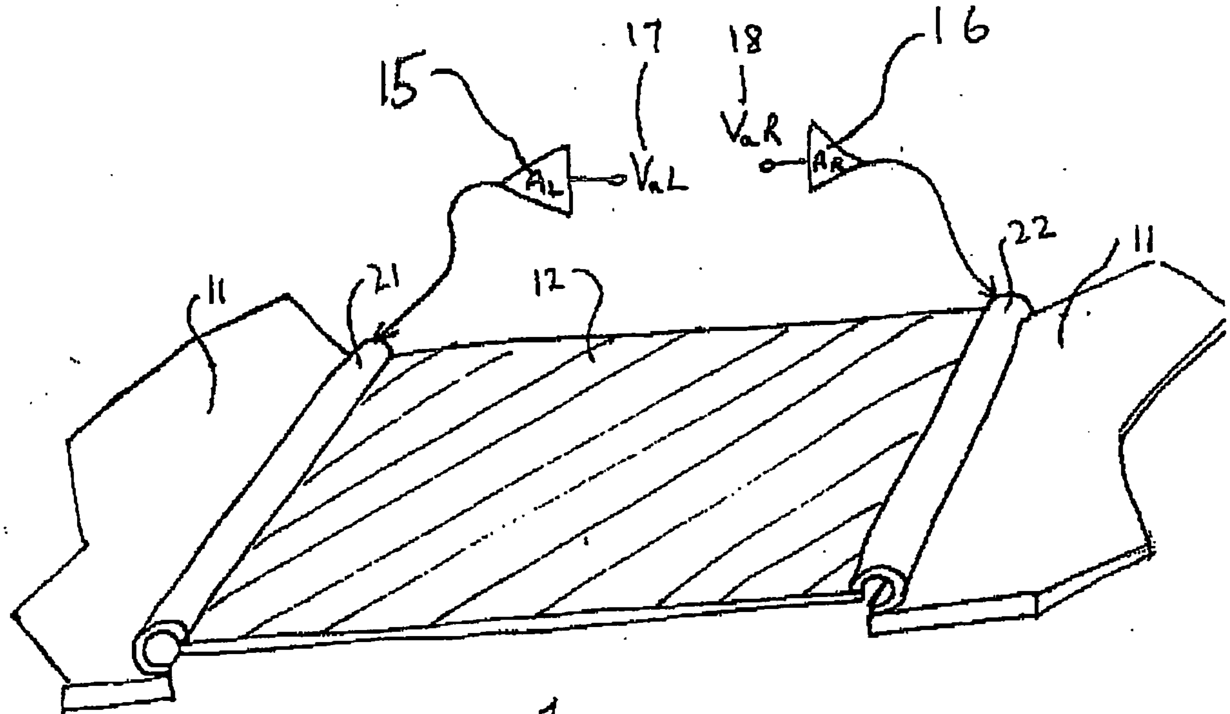

FIG. 1

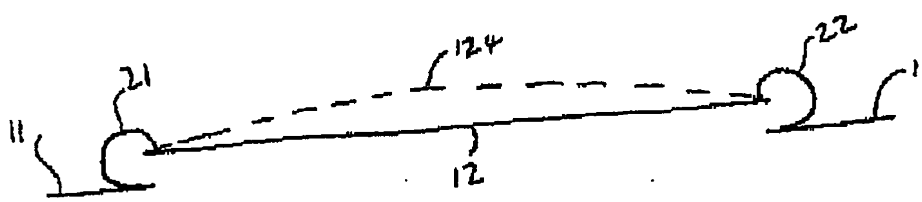

FIG. 3

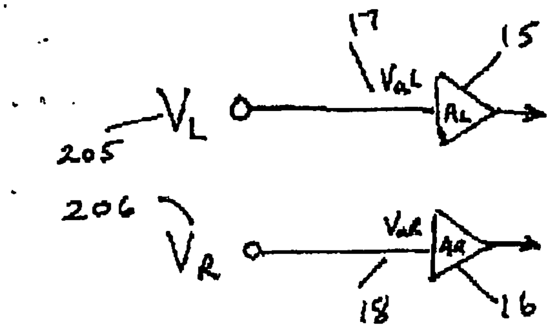

Fig. 2A

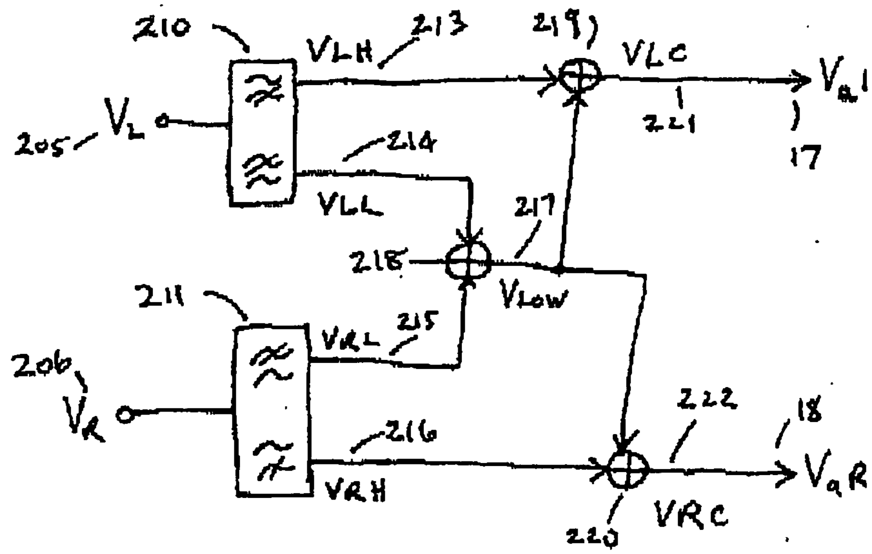

Fig. 2B

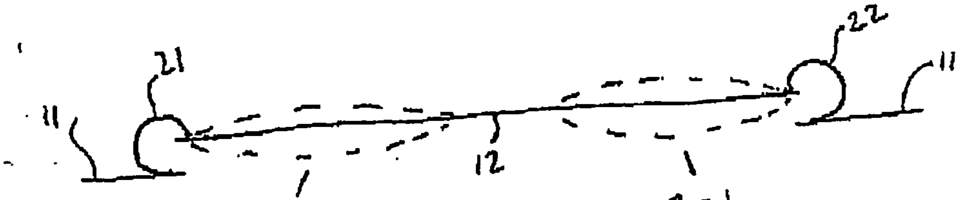

FIG. 4

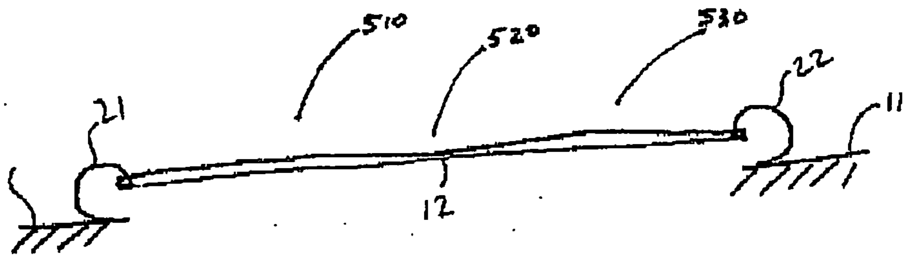

FIG. 5